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# VEGETATION AS INDICATORS OF MINERAL POLLUTION IN A WETLAND RECEIVING ACID MINE DRAINAGE

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## ABSTRACT

Assimilation of metals by vegetation has played a key role in the development of passive treatment technology. Originally, metal assimilation by plants was considered to underpin wetlands' efficacy in treating acid mine drainage (AMD). Subsequent research has shown that other components of wetland systems, such bacteria and attached biomass play a more significant role. Despite this, wetland vegetation provides key insights into the response of a wetland system to mineral pollution. In a South African colliery, a natural wetland has received AMD for the past two decades. Analysis of vegetation for iron and manganese showed that certain species assimilate iron optimally while others assimilate manganese. Storage of metals in plants is an indicator of environmental conditions. Along the wetland axis, plants concentrated differing amounts of metal in their aerial sections and rhizomes. The ratio of metals in rhizomes to that in aerial sections gradually changed with distance from the source of pollution. While iron was preferentially concentrated rhizome tissue, manganese was concentrated in the aerial portions. By dividing the wetland into sections and comparing the mass of metals retained in vegetation over the growing period to the mass of metals imported into each section, polluted groundwater seeps could be identified. Analysis of metal concentration in the vegetation has provided cost-effective insight into the response of the wetland to chronic AMD.

## 1. INTRODUCTION

The ability of wetlands to improve the quality of acid mine drainage (AMD) was first noticed in the Powelson Wildlife Area, Ohio. Researchers from the Wright State University recorded an improvement in pH value co-incident with the precipitation of metals [2]. Wetland (hydrophytic) vegetation was thought to assimilate metals, thereby improving water quality. As more data was collected, it became apparent that other components of wetland systems play important roles.

The moss Sphagnum, also known as peatmoss, was used as the principal component of early constructed wetland systems. Due to hyper-accumulation and resultant toxicity, constructed wetlands receiving high concentrations of iron and manganese experienced die-back within one or two seasons [4]. Consequently, few of these Sphagnum-based systems remain in operation [2]. The emphasis in constructed wetland technology then shifted to the emergent hydrophyte, Typha (cattails). This plant has a large rhizome and root system which influences conditions in the wetland sediments and results in the removal of metals from surrounding water. Iron armouring on the rhizome and roots acts as a natural uptake limiting mechanism, ensuring the survival of the plant, but reducing the effectiveness of the systems relying exclusively on Typha [3].

As water flows through a wetland system, it undergoes a series of quality alterations brought about by complex interactions between the water and vegetation, soils and rock. Processes which promote these alterations include weathering, mineralisation, microbial decomposition, aeration, ion-exchange and nutrient uptake [1]. Wetland biogeochemical processes which improve water quality are assisted by hydrological factors. Current thought emphasises the value of sediment microbes such as Desulfovibrio vulgaris. These reduce sulphate in AMD, increasing water pH value and precipitating metals. In this model plants are primarily regarded as a carbon source and as points of attachment for bacteria.

This paper discusses the use of wetland vegetation as indicators of environmental conditions prevalent in a system.

## 2. CASE STUDY

Pyrite associated with coal and it's surrounding strata often oxidises during and after mining to form the soluble hydrous iron sulphates associated with AMD. South African collieries are no exception in this regard and in one such mine, a natural wetland has received AMD for at least two decades. Various systems have been put in place to ameliorate the impact of this effluent, each with limited degrees of success.

With the increase in environmental awareness amongst both mining companies and legislators in South Africa, more pressure has been exerted to reduce water pollution. To optimise performance of the wetland, an independent sampling programme was run over twelve months. Surface water samples were collected, together with wetland vegetation and sediment samples.

## 3. WATER QUALITIES

Two sets of samples were taken at monthly intervals at sites established throughout the system. The first sample was analysed in the field for pH value, electrical conductivity (EC) oxidation/reduction potential (Eh) and dissolved oxygen (DO). The second sample was sent to a laboratory for analysis. Analyses were made for inter alia, sulphate, heavy metals, ammonia and nitrate.

Polluted water sources were identified around the upper reaches of the liming plant stream where effluent seeps from the evaporation pans, in the upper reaches of stream two, where water seeps out of the old workings, and half-way along the wetland, where a seep transports water along an impermeable dwyka tillite from the floor of the coal.

Initial analysis of sampling results indicated that little improvement in water qualities resulted from wetland action. Data acquired via satellite and through vegetation sampling indicated that significant changes occurred in wetland vegetation along the axis of the system.

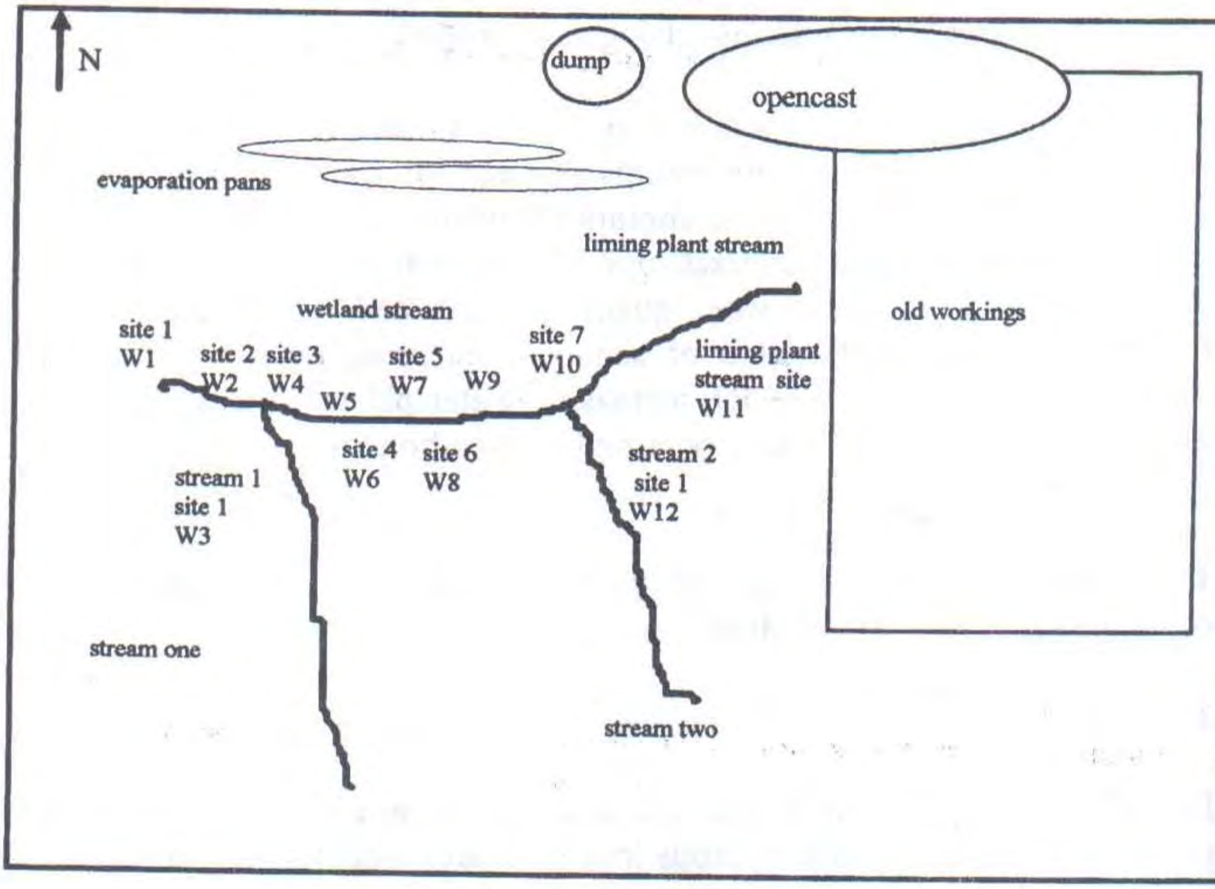


Figure 1. Layout of Sampling sites in the Wetland.

## 4. VEGETATION SAMPLING

Vegetation in the wetland appears to be edaphically controlled with deep rooted species preferentially colonising areas of deep soil. Phragmites is encountered only in soils deeper than 1 m. Typically, these areas are at stream confluences and near seeps, where slumping has promoted soil migration into the wetland. Sedges are found in areas with much shallower soil profiles, typically extending 20 - 30 cm before gravel is encountered. Typha is distributed in zones of intermediate soil depth. The upper portions of the wetland (east) are dominated by sedges, except at the confluence of stream two. This confluence is predominantly colonised by Typha, although Phragmites does occur. Further downstream, Phragmites has colonised two areas which occur adjacent to groundwater seeps. Sediment depth at these locations is greater than for the upper section of the wetland. Towards the confluence of the wetland with stream one, sediment depths increase and the vegetation grades through sedge into Typha and finally into Phragmites. Immediately downstream of the confluence, a rocky outcrop acts as a nick point, effectively damming water further upstream. An acidophilic moss, Sphagnum (peatmoss), has colonised large areas of the wetland of varying soil depths.

Three individual plants of the species Typha, Phragmites, Sphagnum and sedge[1] were collected where they occur on transects. The plants were dug out so as to include the roots and rhizomes. Aerial and root sections were separated before being rinsed and oven dried at 104°C for 24 hours. Metals were extracted by digestion in concentrated nitric acid which was then analysed for iron and manganese.

[1] Sedge is used as a generic term.

Table 1. Vegetation Sampling Locations.

| Water Sampling Site | Location | Vegetation Sampled |
|---|---|---|
| W1 | site 1 | sedge, Phragmites, Sphagnum |
| W2 | site 2 | sedge, Sphagnum, Typha |
| W4 | site 3 | Sphagnum, Typha |
| W6 | site 4 | sedge, Phragmites, Sphagnum |
| W7 | site 5 | sedge, Phragmites, Sphagnum |
| W8 | site 6 | sedge, Phragmites |
| W10 | site 7 | sedge, Typha |
| W3 | stream 1 site 1 | sedge, Phragmites |
| | stream 2 site 1 | sedge |
| W11 | liming plant stream site 1 | sedge |

Water sampling sites which are not on transects occur between site 3 and site 4 (W5) and between site 6 and site 7 (W9). In some figures below, water sites are used instead of transects. The wetland was divided into sections using the water sampling sites. Sampled concentrations in transects were assumed to be representative of metal concentrations in vegetaion over the entire section. Where two transects occur in a section, the averaged value of metal concentrations were applied to the section.

## 5. ANALYSIS OF METAL CONCENTRATIONS IN WETLAND VEGETATION

Concentrations of metal in wetland species are orders of magnitude higher than natural levels. This is due to exposure of the plants to chronic AMD.

Assuming the following plant densities, total biomass (wet mass) may be calculated for the wetland;

- sedge 10 $kg/m^2$
- Phragmites aerial section 20 $kg/m^2$
- Phragmites root section 10 $kg/m^2$
- Typha aerial section 20 $kg/m^2$
- Typha root section 10 $kg/m^2$
- Sphagnum 15 $kg/m^2$

These figures represent conservative estimates of wetland vegetation densities arrived at by consultation with scientists active in this field [6,7].

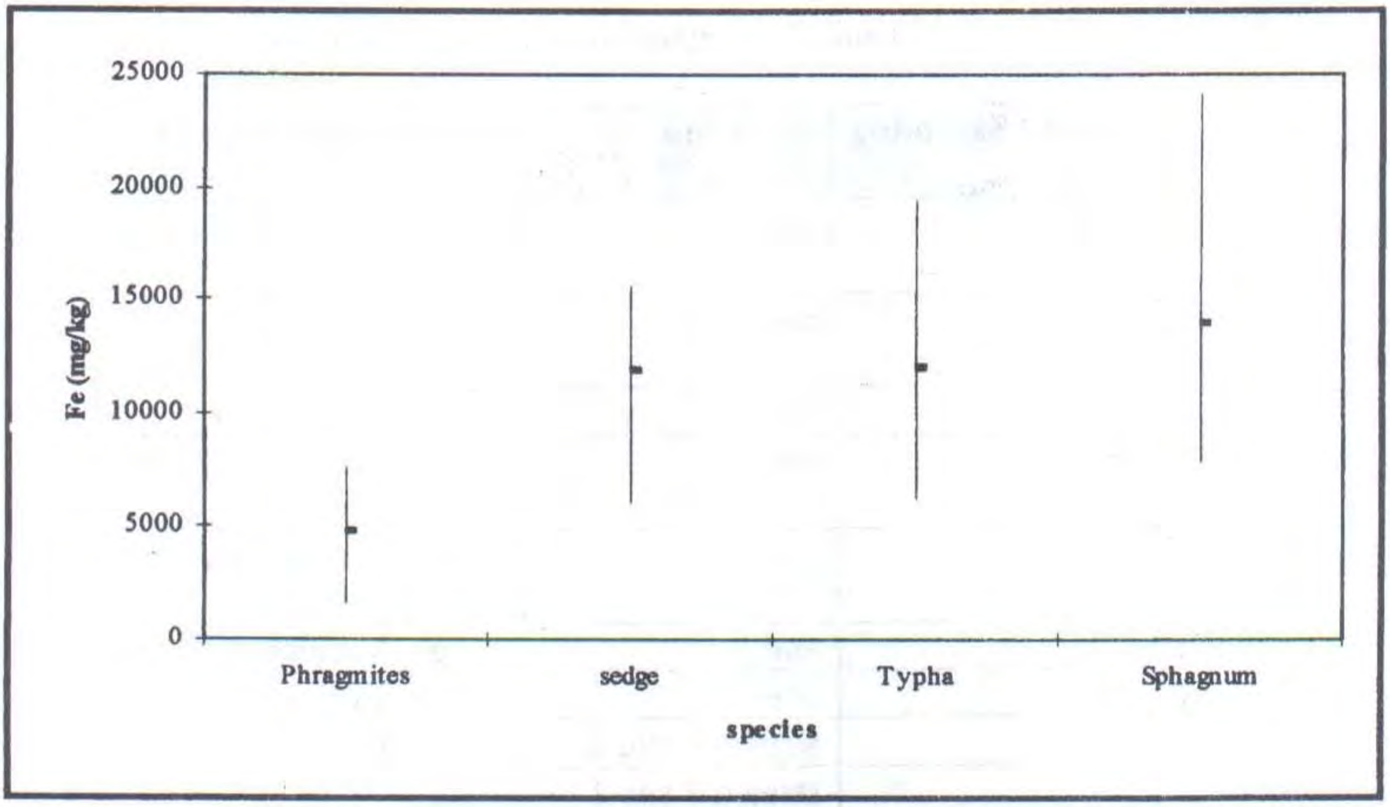


Figure 2. Iron Concentrations Encountered in Vegetation in the Wetland (average values indicated by bars; values for plants split into root and aerial sections are averages of the two analyses).

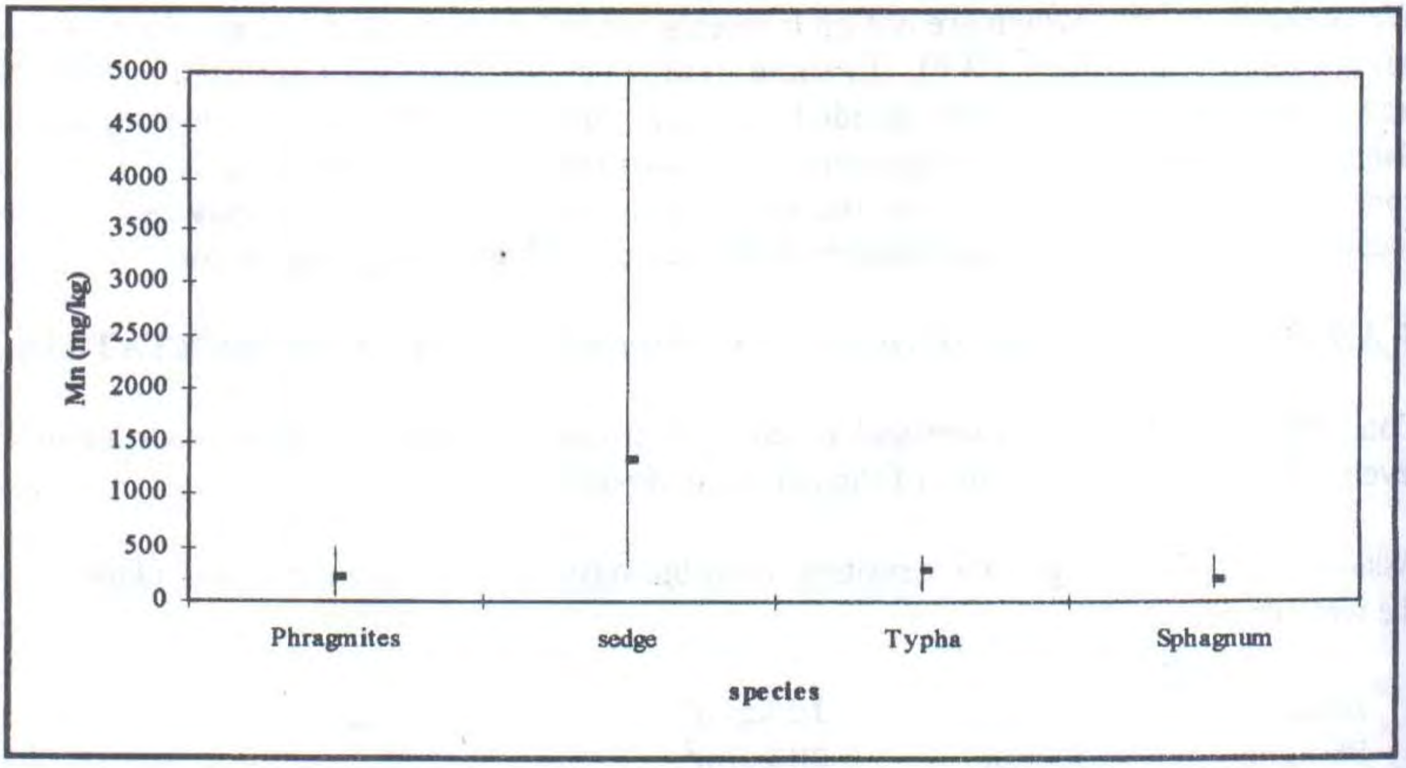


Figure 3. Manganese Concentrations Encountered in Vegetation in the Wetland (average values indicated by bars; values for plants split into root and aerial sections are averages of the two analyses).

Van der Toorn [5] lists a range of dry masses for Phragmites varying from 0.5 to 2 $kg/m^2$. A dry mass of 1.5 $kg/m^2$ for mature plants is assumed for this study (Van der Toorn measured 0.5 $kg/m^2$ for immature plants). Spratt and Wieder [4] report dry mass densities for Typha ranging from 5.8 to 1180 $g/m^2$ with an average value of 554 $g/m^2$ (in autumn). As no data was recorded during the drying of wetland vegetation and no values could be located in the literature, other than those for Phragmites and Typha, a drying factor of 0.075 was obtained by dividing the estimated wet density (biomass) of

Phragmites in the wetland by Van der Toorn's stated dry density. This method was used to calculate the dry densities of Sphagnum and sedge;

- sedge 0.75 $kg/m^2$
- phragmites aerial section 1.00 $kg/m^2$
- phragmites root section 0.50 $kg/m^2$
- typha aerial section 0.40 $kg/m^2$
- typha root section 0.20 $kg/m^2$
- sphagnum 1.13 $kg/m^2$

Plant cover of 75% was assumed throughout the major portion of the wetland. Cover of only 30% was assumed for the extreme upper portions (around site 7) which are sparsely vegetated.

Based on the above assumptions, the mass of metal retained by wetland vegetation in each section was calculated (q.v. figure 5). The concentrations of metals in the wetland vegetation appear to follow a recognisable trend along the system's axis. Concentrations increase just downstream of the centre of the wetland, at site 4. This is in the vicinity of a suspected seep. Iron concentrations (and mass bound in vegetation) are at a maximum here (over 20000 mg/kg in Typha roots). Downstream of this point, manganese concentrations increase as iron concentrations decrease. This appears to follow the order of precipitation of these metals, with manganese only coming out of solution after iron has been removed. Concentrations of iron and manganese in wetland vegetation indicate that improved conditions for metal assimilation occur after the suspected seep.

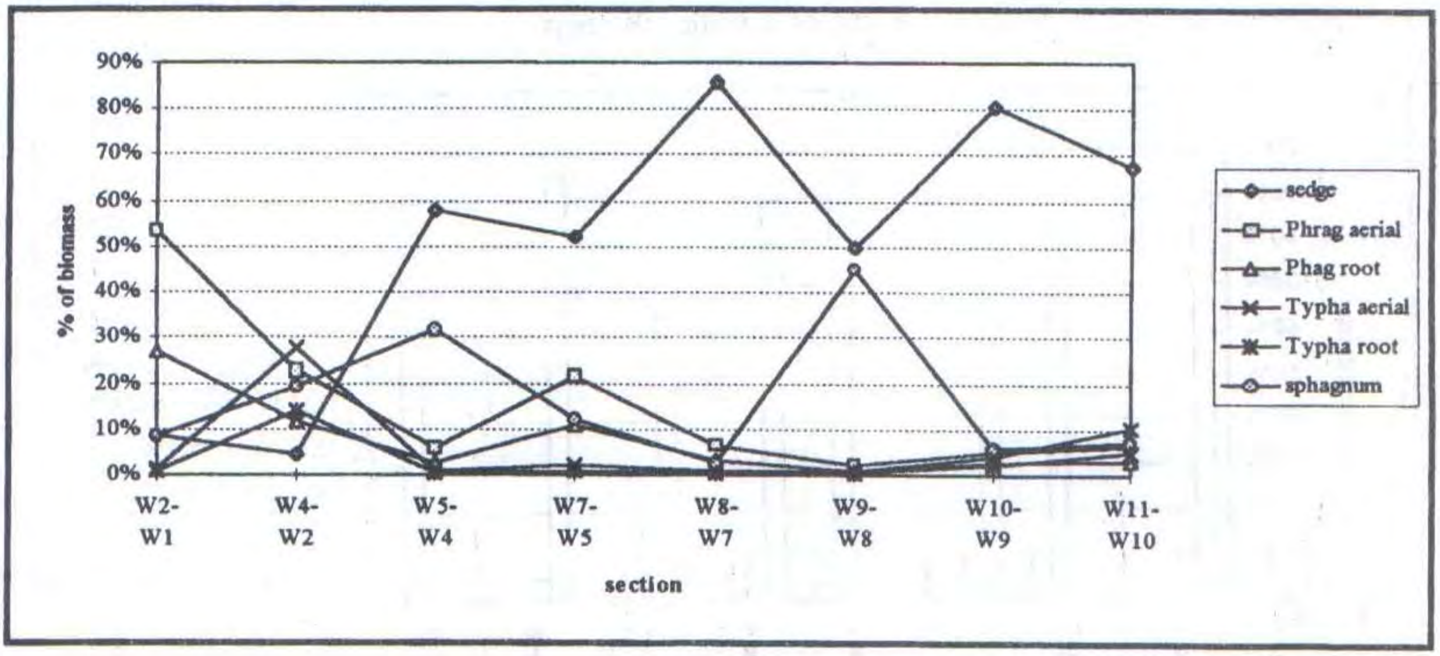


Figure 4. Estimated Composition of Wetland Biomass.

Sediment pH values were not measured during sampling and no correlation can be found between surface water pH values and metal concentrations in plants.

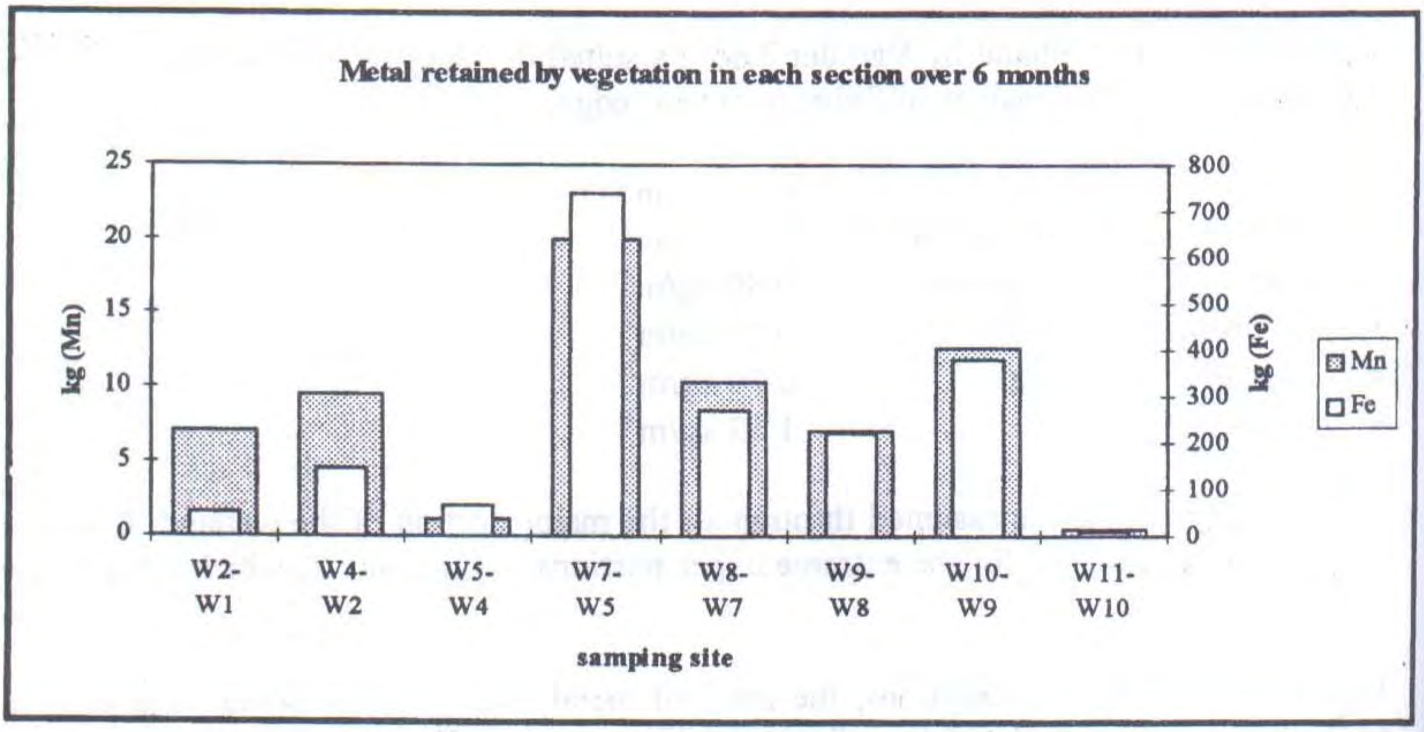


Figure 5. Mass Of Metals Retained in Wetland Biomass in Each Section Over Six Months (the growing season of wetland macrophytes is assumed to be six months).

Typha and Phragmites samples were separated into root and aerial portions before analysis. For iron, the bulk of metal storage occurs in the root/rhizome. This storage is not due to coating by oxyhydroxides as the root material was thoroughly washed before analysis. The buried portion of the plant accounts for between 80% to 95% of the total iron concentration in Phragmites and between 89% to 97% for Typha. At site 5 the contribution to iron storage by aerial sections increases from an average of 11% (Phragmites) to 20%. This is the site of a polluted seep.

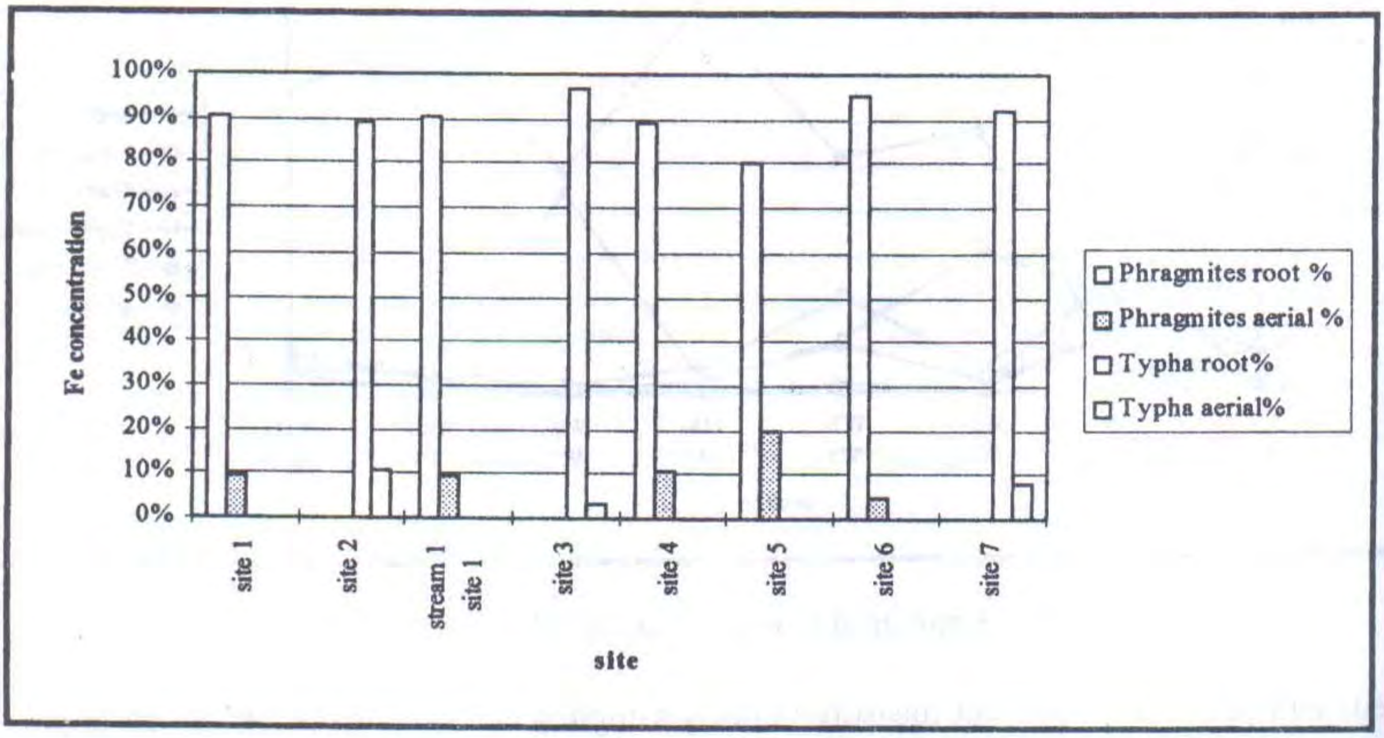


Figure 6. Distribution Of Iron in Emergent Hydrophytes Along the Axis of the Wetland.

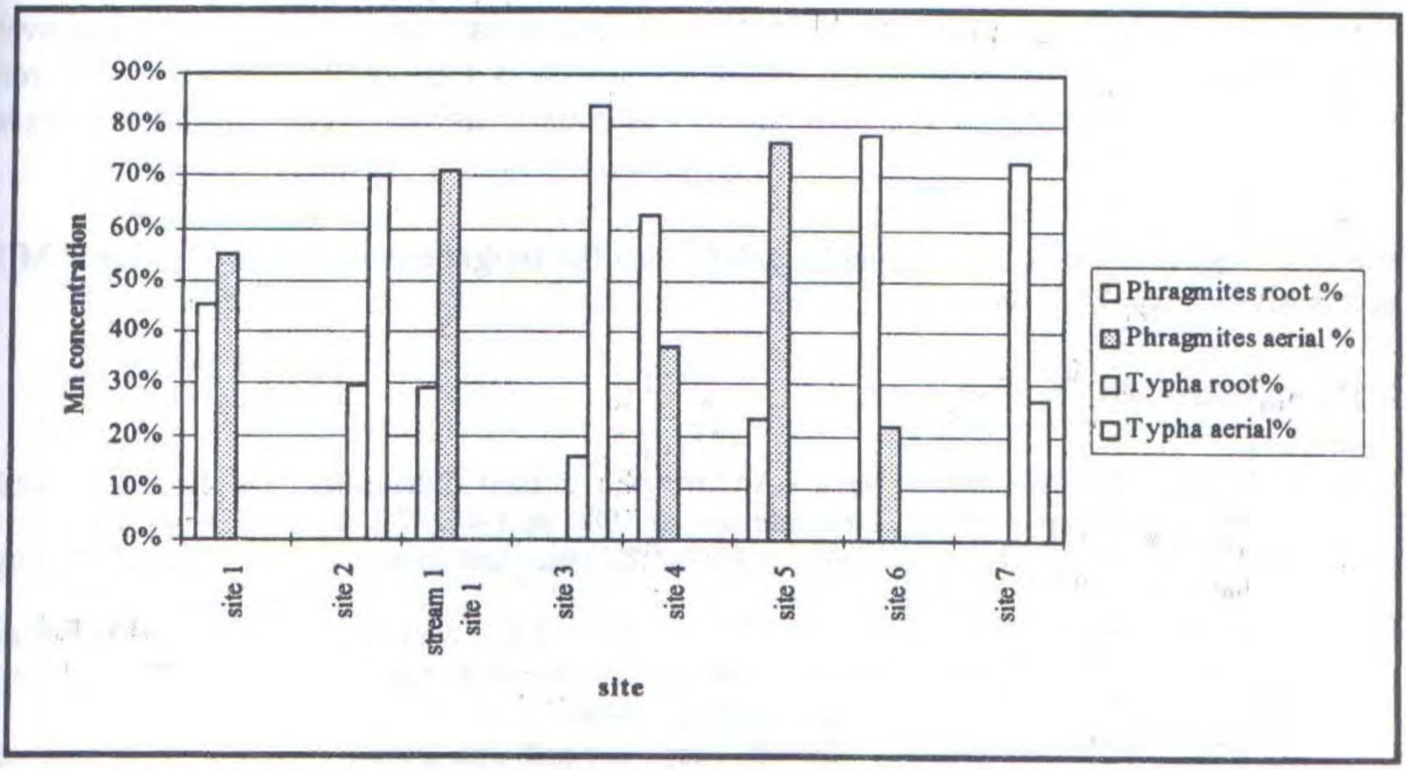


Figure 7. Distribution of Manganese in Emergent Hydrophytes Along the Axis of the Wetland.

Manganese storage is more evenly distributed between aerial and buried portions of the hydrophytes. Root storage contributes between 23% and 63% to total storage for Phragmites and 16% to 73% for Typha. The lowest root concentration contribution occurs at site 5 for Phragmites (23%) and at site 3 for Typha (16%).

## 6. SUMMARY

The maximum concentrations of iron in vegetation were measured at the seep (site 4) and just downstream at site 3. Maximum concentrations of manganese were measured at the last two transects (sites 1 and 2), at the eastern extreme of the system. Thus biogeochemical amelioration processes only predominate in stream 2, and downstream of the seep in the wetland. In other areas, changes in water quality are controlled by the complex process of the mixing of different quality waters.

Table 2. Metal Retained by Wetland Vegetation.

| Species | % of Biomass | Mass of Fe retained (kg) | Mass of Mn retained (kg) |
|---|---|---|---|
| sedge | 56% | 1329 | 53 |
| Phragmites (aerial) | 14% | 26 | 6 |
| Phragmites (root) | 7% | 26 | 0.3 |
| Typha (aerial) | 4% | 8 | 3 |
| Typha (root) | 2% | 205 | 2 |
| Sphagnum | 16% | 559 | 6 |

The average mass of metal imported into the wetland over the sampling period (12 months) was 3.6 t for iron and 16 t for manganese. Of this, 3.3 t of iron and 0.60 t of over this period, although the metals fixed in rhizomes may have been accumulated over longer periods of time. Vegetation in the wetland was thus the sink for 61% of iron entering the system and ~~3.8%~~ of manganese[2]. Amounts assimilated by various species is detailed in Table 2. 0.4

Wetland vegetation provides valuable insight into the biogeochemical alteration of AMD as it moves through the system.

## 7. REFERENCES


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[2] When comparing these figures to values quoted in the literature, bear in mind that this wetland is a very old natural system. Most literature deals with small constructed wetlands that are only a few years